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INDUSTRIAL SAND AND GRAVEL

By Wallace P. Bolen

1989

U.S. DEPARTMENT OF THE INTERIOR
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INDUSTRIAL SAND AND GRAVEL

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COVER PHOTO:
Glass production consumes over 40% of the silica (industrial) sand produced in the United States. Container, dinner, and decorative glasses represent only three of a myriad that are produced for hundreds of applications. (Photo is by Ronald Joseph Prucha, Jr.)

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INDUSTRIAL SAND AND GRAVEL

By Wallace P. Bolen

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Production of industrial sand and gravel in 1989 increased to 29.2 million tons, about a 3% increase over that of 1988. Production increased for the third consecutive year and was attributable to increased silica usage for fiber and specialty glasses, chemicals, roofing granules, and hydraulic fracturing (frac sand).

Exports of silica sand and gravel increased about 94% in quantity and 31% in average value per ton, compared with that of 1988. Imports of industrial sand and gravel decreased about 19% in quantity, but the associated value increased 7%. Domestic apparent consumption of industrial sand and gravel in 1989 was 27.2 million short tons, a small decrease from 1988.

Domestic production data for industrial sand and gravel were developed by the Bureau of Mines from voluntary surveys of U.S. producers. Of the 160 industrial sand and gravel operations surveyed, 153 (96%) reported to the Bureau of Mines. Their combined production represented about 99% of the U.S. total published in table 1. The production of nonrespondents was estimated mostly using employment data. Of the 160 operations, 153 (96%) were active and 7 idle.

LEGISLATION AND GOVERNMENT PROGRAMS

The Department of Labor's Mine Safety and Health Administration (MSHA) issued a proposed rule titled "Air Quality, Chemical Substances, and Respiratory Protection Standards" on August 29, 1989. A section of the proposed rule would revise standards for air quality at metal-nonmetal mines.

For silica, the revision proposed accepting a 0.1 milligram per cubic meter (mg/m^3) of respirable silica (quartz) exposure limit in place of the former formula that measured and limited exposure. This change did not effectively alter the standard but rather conformed the silica exposure limit to the format used for all other hazardous dusts. For cristobalite and tridymite, the less common forms of silica (SiO_2), the proposed exposure limit was 0.05 mg/m^3. Additionally, the proposed rule reviewed current standards on dust control and detailed the use and maintenance of respirators.[1]

ISSUES

A major issue of concern for the silica industry revolved around the 1986 International Agency for Research on Cancer (IARC) findings that there was limited evidence that silica is a carcinogen to humans. A hazard communication statement was required by the Occupational Health and Safety Administration (OSHA) because respirable silica is known to induce silicosis, a noncancerous lung disease, and is considered a probable carcinogen. This meant that employers must inform and train their employees about the proper handling of silica due to its potential hazards.

Additionally, MSHA recommended that producers label products that contain respirable silica to alert their customers of the hazards associated with silica. Many producers have begun this practice, and training of employees has been regular and continuous at most operations. The greatest concern for producers of silica was negative reaction from consuming industries and

TABLE 1

SALIENT U.S. INDUSTRIAL SAND AND GRAVEL STATISTICS[1]

(Thousand short tons and thousand dollars)

	1985	1986	1987	1988	1989
Sold or used:					
Sand:					
Quantity	29,070	26,940	27,380	27,207	27,819
Value	$370,730	$354,460	$357,660	$376,202	$395,807
Gravel:					
Quantity	357	484	631	1,272	1,385
Value	$3,340	$4,853	$6,424	$11,796	$14,388
Total industrial:[2]					
Quantity	29,430	27,420	28,010	28,480	29,205
Value	$374,070	$359,300	$364,100	$388,000	$410,200
Exports:					
Quantity	866	849	758	1,060	2,060
Value	$22,580	$20,363	$21,253	$30,843	$78,308
Imports for consumption:					
Quantity	81	88	104	43	35
Value	$1,513	$1,014	$1,071	$1,918	$2,057

[1] Puerto Rico excluded from all industrial sand and gravel statistics.
[2] Data may not add to totals shown because of independent rounding.

possible additional restrictive legislation and penalties from MSHA and OSHA.

PRODUCTION

The Midwest (East and West North Central regions) continued to lead the Nation in production with about 42% of the 29.2 million tons produced in the United States, followed by the South (South Atlantic, East and West South Central regions) with about 35% and the West (Pacific and Mountain regions) with 14%. Compared with 1988, the output of industrial sand and gravel increased 5% in the South and 3% in the Midwest, but decreased 4% in the Northeast (Middle Atlantic and New England regions) while the West's production increased slightly.

Based on the 1988 census estimations on population, 1989 U.S. per capita industrial sand and gravel production was 0.12 ton. Per capita production by major geographic region was 0.21 ton in the Midwest, 0.12 ton in the South, 0.08 ton in the West, and 0.05 ton in the Northeast.

The five leading States in the production of industrial sand and gravel, in descending order of volume, were Illinois, Michigan, California, New Jersey, and Texas. Their combined production represented 46% of the national total. Significant changes within the five major producing States included Illinois, where production increased 6%, and Michigan, where production decreased by 6%.

The Bureau of Mines canvassed 87 producers of industrial sand and gravel with 153 active operations. About 75% of the industrial sand and gravel was produced by 46 operations, each with

FIGURE 1

PRODUCTION OF INDUSTRIAL SAND AND GRAVEL IN THE UNITED STATES IN 1989, BY GEOGRAPHIC REGION

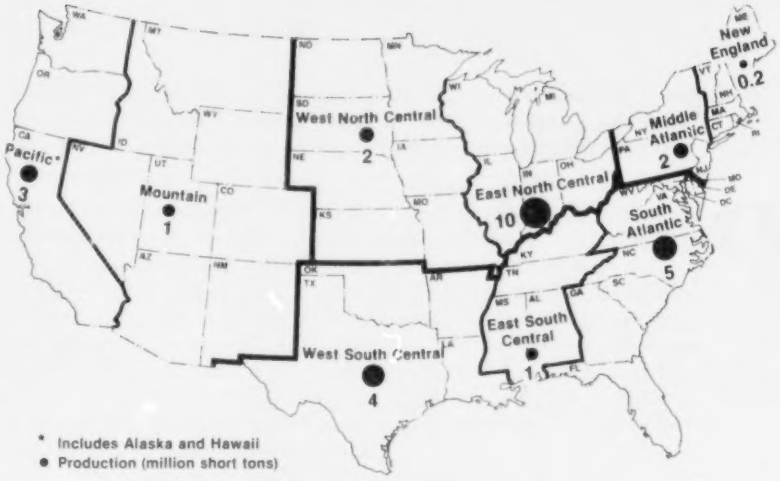

TABLE 2

INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY GEOGRAPHIC REGION

Geographic region	1988				1989			
	Quantity (thousand short tons)	Percent of total	Value (thousands)	Percent of total	Quantity (thousand short tons)	Percent of total	Value (thousands)	Percent of total
Northeast:								
New England	159	1	$4,254	1	154	1	$4,193	1
Middle Atlantic	2,579	9	36,052	9	2,475	8	36,478	10
Midwest:								
East North Central	10,447	37	124,020	32	10,488	36	124,955	30
West North Central	1,595	5	22,701	6	1,881	6	27,108	7
South:								
South Atlantic	4,414	15	65,770	17	4,715	16	71,242	17
East South Central	1,380	5	14,688	4	1,446	5	16,571	4
West South Central	3,885	14	55,595	14	3,994	14	62,589	15
West:								
Mountain	1,272	4	17,607	5	1,315	5	17,657	4
Pacific	2,748	10	47,311	12	2,737	9	49,402	12
Total[1]	28,480	100	388,000	100	29,205	100	410,200	100

[1] Data may not add to totals shown because of independent rounding.

TABLE 3

INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1988		1989	
	Quantity	Value	Quantity	Value
Alabama	871	8,507	805	8,092
Arizona	119	3,045	W	W
Arkansas	669	6,784	545	5,507
California	2,444	42,078	2,426	43,863
Colorado	W	W	W	W
Connecticut	W	W	W	W
Florida	636	6,928	681	7,768
Georgia	W	W	537	7,013
Idaho	483	5,089	459	5,037
Illinois	4,328	56,142	4,582	52,935
Indiana	362	1,829	W	W
Kansas	W	W	230	2,690
Kentucky	—	—	W	W
Louisiana	318	4,786	572	9,664
Maryland	W	W	W	W
Massachusetts	W	W	34	601
Michigan	3,045	27,150	2,865	24,577
Minnesota	W	W	W	W
Mississippi	W	W	W	W
Missouri	744	9,876	750	9,972
Montana	W	W	W	W
Nebraska	W	W	W	W
Nevada	602	W	718	W
New Jersey	1,860	25,437	1,797	26,138
New York	53	625	53	633
North Carolina	1,246	15,953	1,627	19,902
Ohio	1,361	23,441	1,394	24,662
Oklahoma	1,268	17,381	1,216	18,310
Pennsylvania	W	W	W	W
Rhode Island	W	W	W	W
South Carolina	859	15,271	842	16,635
Tennessee	W	W	W	W
Texas	1,631	26,645	1,661	29,107
Utah	3	60	3	60
Virginia	W	W	W	W
Washington	W	W	W	W
West Virginia	W	W	W	W
Wisconsin	1,351	15,458	1,514	22,399
Other	4,228	75,513	3,891	74,630
Total[1]	28,480	388,000	29,205	410,200

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1] Data may not add to totals shown because of independent rounding.

an annual production of more than 200,000 tons. The 10 leading producers of industrial sand and gravel were, in descending order of tonnage, Unimin Corp., U.S. Silica Co., Fairmount Minerals Ltd., The Morie Co. Inc., Manley Brothers of Indiana, Badger Mining Corp., Oglebay Norton Co., Construction Aggregates Corp., Simplot Industries, Inc., and W. R. Bonsal and Co. Their combined production, from 59 operations, represented 71% of the U.S. total.

Green River Silica Co. in Hart County, KY, began operations in 1989 and produced sand for blasting, filtration, and golf courses.

U.S. Silica, based in Berkeley Springs, WV, purchased Card Silica Co., IN, and after renovations expected to begin production in early 1990.

Bonsal, Lilesville, NC, a major producer of industrial gravel for the production of silicon metal, neared completion of another lump silica production facility at Beech Island, SC. The rural dredging operation was located near the Savannah River and Augusta, GA.

The Monterrey City Council refused to renew a mining permit for Monterrey Sand Co., Monterrey County, CA; and, after 46 years of production, the operation ceased activities at its Sand City and Marina beaches locations.

Manley Brothers ceased its operation at Michigan City, IN, because it was unable to obtain additional adjacent reserves as a result of high property costs in the area.

Additionally, 11 small producers of silica sand for industrial uses either ceased operations or moved out of industrial sand production and became solely construction sand producers.

CONSUMPTION AND USES

Sand and gravel production reported by producers to the Bureau of Mines was actually material used by the companies or sold to their customers. Stockpiled material was not reported until consumed or sold.

Of the 29.2 million tons of industrial sand and gravel sold or used, 42% was consumed as glassmaking sand and 24% as foundry sand. Other important uses were abrasive sand (8%) and frac sand (5%). Because some producers

did not report a breakdown by end use, their total production as well as the estimated production for nonrespondents were included in "Other uses, unspecified," which represented about 3% of the U.S. total.

On the regional level, more than one-third of the glassmaking sand was produced in the South (38%), followed by the Midwest (29%), and the West (18%). Three-fourths of the foundry sand was produced in the Midwest (75%). About three-fourths of the hydraulic fracturing sand was produced in the Midwest (74%), and about one-half of the abrasive sand was produced in the South (51%).

Northeast

Cumberland County, NJ, continued to be the largest source for the glass, foundry, and blast sand markets in the region. Unimin, U.S. Silica, Morie, and WHIBCO, Inc., all of which operated plants in the county, were among the largest producers of sand for these markets. U.S. Silica's plant in Huntingdon County, PA, also produced significant amounts of sand for the glass market. Morie's plant in Cumberland County produced a major percentage of the abrasive blast sand in the region.

TABLE 4

INDUSTRIAL SAND AND GRAVEL PRODUCTION IN THE UNITED STATES IN 1989, BY SIZE OF OPERATION

Size range (short tons)	Number of operations	Percent of total	Quantity (thousand short tons)	Percent of total
Less than 25,000	26	17.0	280	1.0
25,000 to 49,999	24	15.6	879	2.9
50,000 to 99,999	26	17.0	1,888	6.5
100,000 to 199,999	31	20.3	4,385	15.0
200,000 to 299,999	11	7.2	2,765	9.5
300,000 to 399,999	11	7.2	3,880	13.3
400,000 to 499,999	9	5.9	4,231	14.5
500,000 to 599,999	4	2.6	2,217	7.6
600,000 to 699,999	4	2.6	2,525	8.6
700,000 and over	7	4.6	6,154	21.1
Total	153	100.0	[1]29,205	100.0

[1]Data do not add to total shown because of independent rounding.

TABLE 5

NUMBER OF INDUSTRIAL SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1989, BY GEOGRAPHIC REGION

Geographic region	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	No plants or unspecified		
Northeast:						
New England	3	—	—	1	—	4
Middle Atlantic	5	—	2	1	6	14
Midwest:						
East North Central	33	1	1	—	2	37
West North Central	7	—	—	—	4	11
South:						
South Atlantic	17	—	—	3	6	26
East South Central	11	—	—	—	2	13
West South Central	12	—	—	2	10	24
West:						
Mountain	7	2	—	—	1	10
Pacific	11	—	—	1	2	14
Total	106	3	3	8	33	153

Midwest

Unimin's plants in LaSalle and Ogle Counties, IL; LeSueur County, MN; and Columbia County, WI; were among the leaders in producing sand for the glass, foundry, frac sand, and blasting markets. Fairmount Minerals, operating plants in Geauga County, OH, and La Salle County, IL, was a major producer for the foundry and glass markets in the region. U.S. Silica's plant in La Salle County, IL, and Badger Mining's plant in Jackson County, WI, were large producers for the glass and frac sand markets, respectively. Construction Aggregates Corp. in Ottawa County, MI, and Manley Brothers in Van Buren County, MI, were major producers of foundry sand in the region. Unimin's Ogle County and Badger Mining's Green Lake County operations were also large producers for the foundry industry.

South

Unimin and U.S. Silica Co. were two of the largest producers of sand for the glass and foundry markets. Unimin's major plants were in Frederick County, VA; Richmond County, NC; Pontotoc County, OK; and Izard County, AR. U.S. Silica's Bullock County, AL; Morgan County, WV; and Johnston County, OK, operations were the major contributors for these markets. Morie's Tuscaloosa County, AL, and Tennessee plants were large producers of foundry and glass sand, respectively, in the region. Pioneer Concrete of Texas, Inc., Southern Silica of Louisiana, Specialty Sand Co., LA, and Foster-Dixianna, SC, produced the bulk of the blasting sand. Bonsal and B. V. Hedrick Sand and Gravel, both in Anson County, NC, produced most of the industrial gravel used in the processing of silicon and ferrosilicon. Bonsal also produced large quantities of material for roofing granules.

West

Owens-Illinois, Simplot Industries, and Unimin were the three largest pro-

TABLE 6

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1989, BY MAJOR END USE

Major use	Northeast			Midwest			South			West			U.S. total[1]		
	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton
Sand:															
Glassmaking:															
Containers	1,276	$17,148	$13.44	2,013	$16,876	$8.38	2,769	$32,595	$11.77	1,800	$30,164	$16.76	7,858	$96,782	$12.32
Flat (plate and window)	W	W	13.54	844	8,304	9.84	1,299	15,501	11.93	W	W	14.66	2,589	30,198	11.66
Specialty	W	W	15.15	387	6,419	16.59	W	W	14.71	7	131	18.71	762	12,049	15.81
Fiberglass (unground)	W	W	10.76	302	3,837	12.71	W	W	25.62	105	1,681	16.01	837	15,539	18.57
Fiberglass (ground)	—	—	—	W	W	15.08	W	W	31.88	W	W	20.89	247	6,463	26.17
Foundry:															
Molding and core	430	6,196	14.41	5,095	51,864	10.18	1,093	12,443	11.38	131	2,273	17.35	6,749	72,776	10.78
Molding and core facing (ground)	—	—	—	W	W	26.93	—	—	—	—	—	—	W	W	26.93
Refractory	W	W	5.40	330	1,942	5.88	—	—	—	W	W	33.00	336	2,002	5.96
Metallurgical:															
Silicon carbide	—	—	—	W	W	11.70	—	—	—	—	—	—	W	W	11.70
Flux for metal smelting	—	—	—	W	W	6.96	W	W	3.83	13	80	6.15	45	285	6.33
Abrasives:															
Blasting	212	4,184	19.74	446	6,653	14.92	1,175	22,590	19.23	455	8,763	19.26	2,287	42,190	18.45
Scouring cleansers (ground)	W	W	32.50	W	W	25.68	W	W	56.00	—	—	—	W	W	26.51
Chemicals (ground and unground)	W	W	27.33	376	3,073	8.17	338	5,211	15.42	W	W	16.18	817	10,580	12.95
Fillers (ground):															
Rubber, paints, putty, etc.	25	711	28.44	55	3,512	63.85	71	6,095	85.85	8	136	17.00	159	10,454	65.75
Silica flour	—	—	—	W	W	27.11	W	W	24.14	—	—	—	68	1,781	26.19
Ceramic (ground):															
Pottery, brick, tile, etc.	W	W	41.10	132	3,898	29.53	94	3,150	33.51	W	W	39.00	238	7,537	31.67
Filtration	89	1,619	18.19	W	W	23.50	152	2,662	17.51	W	W	27.42	310	6,033	19.46
Traction (engine)	37	152	4.11	185	1,650	8.92	66	661	10.02	23	439	19.09	311	2,902	9.33
Coal washing	—	—	—	W	W	28.36	—	—	—	—	—	—	W	W	28.36
Roofing granules and fillers	W	W	34.24	89	1,242	13.96	561	8,067	14.38	W	W	21.26	790	13,453	17.03
Hydraulic fracturing	—	—	—	1,126	25,430	22.58	W	W	21.97	W	W	27.22	1,531	34,494	22.53
Other uses, specified	551	10,437	18.94	576	12,163	21.12	1,313	27,756	21.14	1,095	19,910	18.18	XX	XX	XX

See footnotes at end of table.

TABLE 6—Continued

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1989, BY MAJOR END USE

Major use	Northeast			Midwest			South			West			U.S. total[1]		
	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton
Sand—Continued															
Other uses, unspecified[2]	W	W	$27.00	223	2,802	$12.57	450	5,388	$11.97	W	W	$20.07	810	10,940	$13.51
Total[1] or average	2,620	40,449	15.44	12,178	149,662	12.29	9,382	142,119	15.15	3,638	63,577	17.48	27,819	395,807	14.23
Gravel:															
Metallurgical:															
Silicon, ferrosilicon	—	—	—	W	W	10.00	W	W	11.13	—	—	—	758	8,295	10.94
Filtration	8	W	W	W	W	8.33	W	W	9.03	—	—	—	48	591	12.31
Nonmetallurgical flux	—	—	—	—	—	—	W	W	8.78	W	W	8.43	508	4,311	8.49
Other uses, specified	—	—	—	190	W	W	772	8,282	10.73	414	3,481	8.41	XX	XX	XX
Total[1] or average	8	W	W	190	W	W	772	8,282	10.73	414	3,481	8.41	1,385	14,388	10.39
Grand total[1] or average	2,629	W	W	12,369	W	W	10,155	150,401	14.81	4,053	67,059	16.55	29,205	410,200	14.05

W Withheld to avoid disclosing company proprietary data; included with "Other uses, specified;" also included in "U.S. total" by use. XX Not applicable.
[1]Data may not add to totals shown because of independent rounding.
[2]Mostly estimated total production plus other uses (small quantities) as reported by producers.

ducers of glass sand in the region, with major operations in Amador County, CA; Clark County, NV; and Contra Costa County, CA; respectively. Corona Industrial Sand Co., Riverside County, CA, supplied the majority of sand for the sand blasting industry in the region. Simplot Industries also supplied a large portion of the foundry sand consumed.

TRANSPORTATION

Of the total industrial sand and gravel produced, 58% was transported by truck from the plant to the site of first sale or use, up from 56% in 1988; 34% was transported by rail, unchanged from 1988; 3% by waterway, down from 4% in 1988: and 5% not transported, down from 6% in 1988. Because most of the producers did not report shipping distances or cost per ton per mile, no transportation cost data were available.

FIGURE 2

SAND USED IN SELECTED END USES, 1989

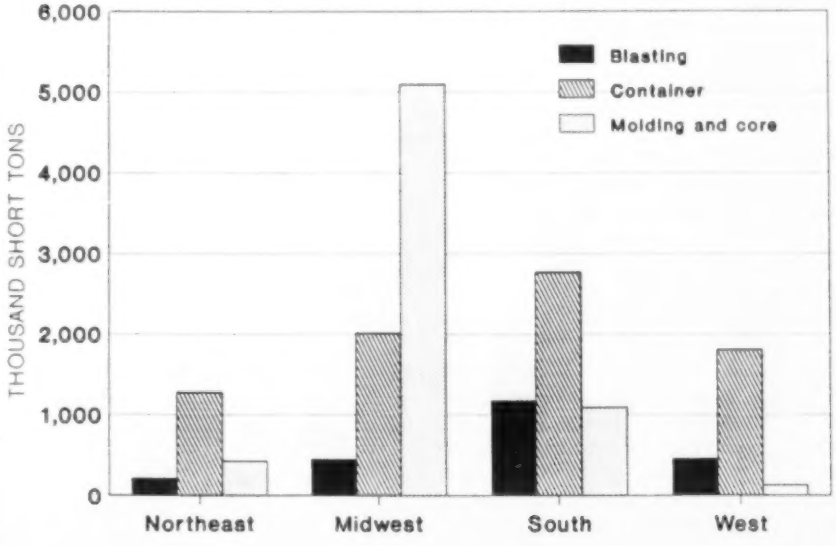

TABLE 7

TRANSPORTATION OF INDUSTRIAL SAND AND GRAVEL IN THE UNITED STATES IN 1989 TO SITE OF FIRST SALE OR USE

Method of shipment	Quantity (thousand short tons)	Percent of total
Truck	16,863	58
Rail	9,949	34
Waterway	825	3
Not transported	1,568	5
Total	29,205	100

PRICES

Compared with 1988, the average value, f.o.b. plant, of U.S. industrial sand and gravel increased nearly 3% to $14.05 per ton. Average unit values for industrial sand and industrial gravel were $14.23 and $10.39 per ton, respectively. Nationally, industrial sand used as fillers for rubber, paint, and putty, etc., had the highest value per ton ($65.75), followed by silica sand used in ceramics ($31.67), coal washing ($28.36), molding and core facings ($26.93), scouring cleansers ($26.51), silica flour ($26.19), and fiberglass (ground) ($26.17).

The average value per ton of industrial sand was highest in the West ($17.48), followed by the Northeast ($15.44), the South ($15.15), and the Midwest ($12.29). Glass sand average value per ton varied markedly, from $16.50 in the West to $10.11 in the Midwest. Tighter supplies and higher production and transportation cost in the West increased the cost of sand and gravel in this region.

FOREIGN TRADE

Exports

Exports of industrial sand, compared with 1988, increased 94% to 2,060,000 tons, and the value increased 154% to $78.3 million. Of this, 51% went to Canada, 21% went to the Netherlands, 7% went to Japan, and the remainder went to numerous other countries throughout the world.

TABLE 8

U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1988		1989	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
North America:				
Bahamas	6	58	(2)	30
Canada	790	11,260	1,054	11,374
Mexico	67	2,284	40	1,631
Panama	5	86	1	34
Other	26	501	5	642
Total[3]	893	14,189	1,100	13,709
South America:				
Argentina	(2)	51	(2)	137
Chile	2	450	4	275
Colombia	1	105	5	54
Ecuador	7	176	(2)	194
Peru	14	747	8	214
Venezuela	3	296	15	184
Other	1	152	6	386
Total[3]	29	1,977	39	1,445
Europe:				
Belgium	15	974	37	937
Finland	2	48	1	22
France	1	222	1	86
Germany, Federal Republic of	8	1,006	62	1,805
Italy	6	654	2	672
Netherlands	12	4,737	426	2,850
United Kingdom	12	579	90	2,116
Other	2	424	4	607
Total[3]	57	8,643	622	9,095
Asia:				
Indonesia	6	662	9	476
Japan	9	1,407	148	47,723
Korea, Republic of	6	424	50	1,687
Malaysia	15	298	(2)	35
Singapore	19	1,514	45	2,232
Taiwan	10	493	9	507
Other	7	373	8	665
Total[3]	71	5,172	270	53,324
Middle East and Africa:				
Saudi Arabia	(2)	16	(2)	9
South Africa, Republic of	5	259	(2)	27
United Arabic Emirates	2	123	(2)	4
Other	2	191	2	274
Total[3]	9	588	2	314
Australia	1	241	25	356
Oceania	(2)	33	(2)	64
Grand total[3]	1,060	30,843	2,060	78,308

[1] Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

Imports

Compared with 1988, imports for consumption of industrial sand decreased 19% to 35,000 tons valued at $2.1 million. Of this, 91% came from Australia and 6% came from Japan. Small amounts of specially prepared silica sand from Canada, the Federal Republic of Germany, France, Japan, Mexico, and the United Kingdom sold for very high values per ton.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL SAND, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1988		1989	
	Quantity	C.i.f. value[1]	Quantity	C.i.f. value[1]
Antigua	36	264	—	—
Australia	(2)	874	32	874
Canada	1	47	1	191
Germany, Federal Republic of	(2)	556	(2)	240
Japan	(2)	2	2	262
United Kingdom	(2)	27	1	60
Other	5	147	(2)	430
Total[3]	43	1,918	35	2,057

[1] Value of material at U.S. port of entry; based on purchase price and includes all charges (except U.S. import duties) in bringing material from foreign country to alongside carrier.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

WORLD REVIEW

World production of industrial sand and gravel, based on information usually provided by foreign Governments, was estimated to be 137.5 million short tons. The United States was the leading producer followed by, in descending order, the Netherlands, Argentina, France, and the Federal Republic of Germany. Most countries in the world had some production and consumption of industrial sand and gravel because of its basic uses in glass and foundries. However, because of variation in descriptions and usage for silica sand and gravel, it was difficult to get reliable information. Beyond those countries listed in table 10, many other countries, including the U.S.S.R. and other Eastern European nations, were believed to have had some type of silica production and consumption.

CURRENT RESEARCH

Research related to the industrial sand and gravel industry continued to advance on many fronts. Newly fabricated materials, including chemicals, ceramics, and other related materials, provided new markets for silica producers while simultaneously placing more stringent requirements on silica as a raw material.

During 1989, several articles were centered on the use of silicon nitride (Si_3N_4), a ceramic, for engine components. Si_3N_4 components had begun to replace traditional metals in engines, functioning in many applications, including turbocharger rotors, valves, and ball bearings. Advantages of Si_3N_4 included improved durability, lower wear and friction, increased fuel efficiency, and greater impact resistance. As materials and production costs come down, usage of Si_3N_4 and other ceramics, such as silicon carbide, could become commonplace.[2 3]

Advances in glass melting technologies will be necessary for the glass industry to remain competitive with alternate materials. Partially funded by the Department of Energy (DOE), Air Products and Chemicals, Allentown, PA, experimented with using oxygen in place of air to improve the efficiency of the furnaces used in glassmaking. Improved efficiency was realized because oxygen raises the flame temperature and minimizes heat losses to the flue.[4] Additionally, KTG Glassworks Technology Inc., Pittsburgh, PA, worked to improve thermal efficiency through the use of segmented furnaces. The system, called Seg-Melt, maintained the separate processing of batch and cullet at the furnace. According to KTG, this method will cut the cost of container glass by 11%.[5]

The DOE continued work on the Defense Waste Processing Facility near Aiken, SC. The operation will use a vitrification process to secure waste of radioactive liquid plutonium by fusing the waste with borosilicate particles to form a glass. The glass will be poured into stainless steel canisters and then sealed before being moved to the glass waste storage building. Eventually the canisters will be stored in the DOE's permanent underground waste facility at Yucca Mountain, NV. Commencement of the process was scheduled for 1992 and should continue for at least 20 years.[6 7]

OUTLOOK

Demand

The forecast range of total U.S. demand in the year 2000 was expected to be 30 to 41 million short tons for industrial sand and gravel. Probable demand was expected to be about 36 million tons, which corresponded with an average annual growth rate of 1.9%. All forecasts were based on previous performances for this commodity within various end uses and contingency factors considered relevant to the future of the commodity.

Glass Sand

Since 1984, annual demand for glass sand had fluctuated between 10.3 and 12.1 million tons. Sand consumed for container glass had decreased since 1987 mainly because some glass containers were being replaced by aluminum cans and plastic containers and also because the amount of glass being recycled was increasing. Additionally, many manufacturers of container glass were using thinner walls in glass containers, and this process had cut down

TABLE 10

INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina	12,513	11,452	9,974	10,455	10,470
Australia	2,304	2,305	2,602	2,170	2,210
Austria	810	880	754	833	830
Belgium	2,169	2,275	2,500	2,690	2,900
Brazil	2,409	3,019	2,829	2,880	2,980
Canada	2,106	2,911	2,934	2,987	3,000
Chile[e]	330	330	330	330	330
Cuba	708	546	571	[e]610	610
Denmark	2	2	[e]2	2	2
Ecuador[e]	55	55	55	55	55
Egypt[3]	[e]140	[e]140	257	38	37
Finland	246	256	257	300	300
France	6,076	5,878	8,236	[e]8,250	8,250
Germany, Federal Republic of	7,739	7,228	6,755	6,386	6,600
Greece[e]	40	40	40	45	45
Guatemala	25	25	34	35	34
Hungary	617	572	696	714	720
Iceland	5	4	5	[e]5	13
India	3,368	1,856	4,173	2,671	3,420
Ireland	7	7	6	7	8
Italy	4,850	4,630	4,740	4,740	4,960
Jamaica	18	14	22	14	17
Japan	4,836	4,327	4,291	4,630	[4]4,826
Kenya	([3])	([3])	([e 5])	([e 5])	[4]12
Korea, Republic of	1	1	1	2	2
Luxembourg	2	—	—	—	—
Mexico	1,630	977	1,065	1,021	[4]1,137
Netherlands	22,033	25,178	24,553	28,659	28,270
New Zealand[e]	55	55	55	[4]61	60
Norway[e]	855	880	880	880	880
Pakistan	223	127	164	148	140
Paraguay	1,653	2,094	2,111	2,105	2,105
Peru	2,096	5,343	8,833	[e]5,510	5,510
Philippines	[e]165	[e]165	185	281	240
Portugal[e]	6	6	6	6	6
South Africa, Republic of	1,673	1,824	2,135	2,216	[4]2,405
Spain	2,507	2,888	1,707	2,205	2,205
Sweden[e]	760	770	770	770	770
Tanzania	10	10	7	13	10
Thailand	168	169	169	267	270
Turkey	399	[e]420	438	[e]440	440
United Kingdom	4,605	4,528	3,599	4,740	4,630
United States (sold or used by producers)	29,430	27,420	28,010	28,480	[4]29,205
Venezuela[e]	3,750	3,860	4,200	4,200	4,200

See footnotes at end of table.

the amount of sand used. Also, a new, thinner and lighter safety glass was used in automobiles and its use was growing. As a result of these contingency factors, demand for glass sand was expected to grow slowly until the year 2000. Probable demand for glass sand for the year 2000 was forecast to be 14 million tons, with a range of 12 to 16 million tons. The probable forecast indicated a modest annual growth rate of 0.8%.

Foundry Sand

The probable forecast for foundry sands was expected to be 9.5 million tons, and the range was expected to be 9 to 11 million tons. The probable forecast indicated an average annual growth rate of 2.6%. The use of foundry sand was seen to be dependent mainly on automobile production. Recently, many foreign auto makers have opened plants in the United States, and this should support growth in sales of foundry sands as a greater percentage of cars sold in the United States will also be made in this country.

Hydraulic Fracturing Sand

This end use showed a strong growth in 1989, surging to over 1.5 million tons. The amount of hydraulic fracturing sand used in each oil and gas well increased, and this trend was expected to be maintained in the future. Therefore, demand was expected to grow for this end use. Probable demand for hydraulic fracturing sand for the year 2000 was expected to be 2.3 million tons, with a range of 1.7 to 2.7 million tons. The probable forecast indicated an annual growth rate of 4%.

Adequacy of Supply

Domestic production was expected to continue to meet more than 99% of demand through the year 2000. Imports, mostly from Australia, the Bahamas, and Canada, were expected to remain minor.

The United States was the largest producer and consumer of silica sand among the market economy countries and was self-sufficient in this commodity. Most of it was produced in the eastern part of the United States where the largest deposits and major markets were located. A significant amount of silica sand was also produced in the West and Southwest, mostly in Califor-

TABLE 10—Continued

INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[e]	1989[e]
Yugoslavia	2,905	2,939	2,379	2,231	2,320
Zimbabwe	113	159	45	61	[4]68
Total[6]	126,413	128,566	133,375	135,143	137,501

[e] Estimated. [p] Preliminary.

[1] Table includes data available through June 15, 1990.

[2] In addition to the countries listed, Angola, Antigua and Barbuda, the Bahamas, China, Israel, New Caledonia, Panama, and the U.S.S.R., among others, produce industrial sand, but current available information is not adequate to formulate estimates of production levels.

[3] Fiscal years beginning July 1 of that stated.

[4] Reported figure.

[5] Less than 1/2 unit.

[6] Data may not add to totals shown because of independent rounding.

nia and Texas.

Because the unit price of silica sand was relatively low, except for a few end uses that required a high degree of processing, the location of silica sand deposits in relation to the market was an important factor that may work for or against a sand producer. Consequently, a significant number of relatively small operations supplied local markets with a limited number of products.

The constant-dollar price of domestic silica sand had fluctuated since 1983 and was expected to continue fluctuating because of strong competition among producers for retention of dwindling markets.

Possible Supply-Demand Changes

Several factors could affect supply-demand relationships for silica sand. Further increases in the development of substitute materials for glass and cast metals could reduce demand for glass sand and foundry sand but would increase demand for silica flour, which is used as a filler in plastics, and for glass fibers, which are used in reinforced plastics. Also, increased efforts to reduce waste and increase recycling could hinder glass sand demand. Although these developments could cause demand for silica sand to decrease, the total value of production could increase because of the increased unit value of the new specialized sands.

An increase in the price of oil on the international market would stimulate domestic drilling and extraction from new and old oil deposits. This would increase demand for domestic hydraulic fracturing sand.

Concern over the use of silica as an abrasive due to health concerns and the imposition of stricter legislative and regulatory measures concerning silica exposure could decrease demands in many silica markets.

Development of more efficient mining and processing methods were expected to continue. This will enhance development of lower grade silica sand deposits located closer to markets but not presently mined. Such developments were expected to increase silica sand reserves.

BACKGROUND

Probably no other nonmetallic mineral has more diversified uses than silica sand, mainly because of its common occurrence around the world and its distinctive physical characteristics, including hardness, resistance to high temperature and chemical action, and relatively low price. One of the first industries to use silica sand was the glass industry. At least 4,000 years ago, long before iron was smelted, glassmaking was already a known craft. Although the place and date of the first manufactured glass are not known, the oldest known specimens of glass are from Babylon (ca.2600 B.C.) and from Egypt (ca.2500 B.C.), where the industry was well established by around 1500 B.C. Many varieties of glass were known during Roman times. Little is known of the glassmaking methods used in Europe from the fall of Rome until the 10th century, when stained glass was produced in Venice. After this, Venice remained the leader in fine glassware for the next four or five centuries. In the 17th century, a process for casting glass was invented in France, and later England began to make flint glass, marking the beginning of modern glass technology.

Glassmaking was apparently the first industry to be transplanted from Europe to North America, first to Mexico, and later to the British colonies. The first manufacturing establishment in what is now the United States was a glass factory at Jamestown, VA, built in 1608. The 1885 edition of "Mineral Resources of the United States," the predecessor of today's Bureau of Mines "Minerals Yearbook," reported a total of 317,000 tons of silica sand produced in 1884 in the United States, under "Glass Materials." In 1989, a total of 29.2 million tons of silica sand was produced in the United States for a variety of uses, of which 12.3 million tons was for glassmaking. Today, glass has become an invaluable product with a multitude of forms and applications.

TABLE 11

TIME-PRICE RELATIONSHIP FOR SILICA SAND

Year	Average annual price, dollars per ton, f.o.b. quarry	
	Actual price	Based on constant 1988 dollars
1970	$3.47	$10.02
1971	3.49	9.53
1972	3.81	9.94
1973	3.80	9.31
1974	4.83	10.85
1975	5.50	11.25
1976	5.70	10.96
1977	6.82	12.29
1978	7.65	12.85
1979	8.57	13.23
1980	9.98	14.13
1981	11.15	14.39
1982	12.03	14.59
1983	12.63	14.75
1984	12.92	14.55
1985	12.75	13.95
1986	13.16	14.03
1987	13.06	13.49
1988	13.83	13.83
1989	14.23	13.67

Metals casting was probably the second industry that used silica sand. Today, the casting industry provides vital components for most modern manufacturing industries. The number of industries using silica sand is growing constantly, as are the products made by using silica sand.

Definitions, Grades, and Specifications

Sand is defined throughout the industry and by the American Society for Testing and Materials (ASTM) as granular rock particles that pass through a No. 4 mesh (0.187-inch) U.S. standard sieve and are retained on a No. 200 mesh (0.0029-inch) sieve, and are the result of natural disintegration or comminution of cemented rock. Industrial sand or silica sand is the term used by the industry for sands that have a very high percentage of silicon dioxide (SiO_2), and are essential materials in glass manufacture, in ferrous and nonferrous foundry operations, in certain chemical and metallurgical processes, for hydraulic fracturing of oil and gas deposits, and in many manufactured products as fillers or extenders.

Most industrial sands have been named for their specific uses; for example, glass, foundry, abrasive, filler, and hydraulic fracturing sands. Almost invariably these sands, in addition to being high in silica, consist mostly of quartz grains.

TABLE 12

PROJECTIONS AND FORECASTS FOR U.S. INDUSTRIAL SAND, BY END USE, IN THE YEAR 2000

(Million short tons)

End use	1989	Year 2000		
		Forecast range		Probable
		Low	High	
Glass sand	12.3	12.0	16.0	14.0
Foundry sand	7.1	9.0	11.0	9.5
Hydraulic fracturing sand	1.5	1.7	2.7	2.3
Other	8.3	8.0	11.0	10.0
Total	29.2	30.7	40.7	35.8

Products for Trade and Industry

Silica sand had a wide range of uses in a significant number of industries, the most important being glass and foundry. Other uses were metallurgical and as abrasives, as fillers, for filtration, and for hydraulic fracturing of rock formations to improve recovery in oil wells.

Glass sand was used as a main constituent for manufacturing glass containers, flat glass, safety glass, pressed and blown glass, fiberglass, and a wide variety of specialty glasses such as optical glass and industrial glass.

Glass sand had to meet rigid specifications with respect to purity and silica content, depending on the kind of glass being manufactured. Only a very small amount of iron oxide and chromium compounds could be tolerated, and a high percentage of aluminum, calcium, or magnesium oxides was undesirable. The standards of the American Ceramic Society for glass sand indicated that all grains should pass through a No. 20 mesh screen, between 40% and 60% should be retained on a No. 60 screen, between 10% and 20% on a No. 80 screen, and not more than 5%

TABLE 13

TEN-YEAR STATISTICAL DATA FOR INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS, BY SELECTED END USES

(Thousand short tons)

End use	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Glass[1]	12,905	12,078	12,252	9,436	11,341	10,293	10,993	11,873	12,141	12,293
Foundry[2]	9,036	9,948	7,118	6,670	7,239	5,143	5,777	[3]6,932	7,610	[3]7,085
Silicon carbide	156	463	140	94	135	121	W	130	W	W
Flux for metal smelting	141	246	191	74	97	67	46	114	117	45
Abrasive[4]	1,928	1,958	2,208	1,950	2,030	1,681	1,947	[5]1,848	2,113	[5]2,287
Chemicals	456	426	335	271	425	378	317	513	655	817
Fillers	225	284	192	141	200	158	267	394	225	227
Ceramics	148	179	226	179	184	150	198	225	280	238
Filtration	234	249	299	102	217	345	494	433	407	310
Traction (engine)	403	398	450	195	246	292	177	465	305	311
Roofing granules and fillers	203	162	517	296	289	403	261	392	575	790
Hydraulic fracturing	1,177	1,407	1,481	990	2,057	2,102	1,130	1,396	1,299	1,531

W Withheld to avoid disclosing company proprietary data.
[1]Includes container, flat, specialty, and fiber (sand and ground sand).
[2]Includes molding and core, molding and core facings (ground).
[3]Excludes molding and core facings (ground).
[4]Includes blasting, sawing and sanding (1980-82,1984-86), and scouring cleansers (ground).
[5]Excludes scouring cleansers (ground).

should pass a No. 100 screen. Sand for first-quality optical glass should contain 99.8% SiO_2 and a maximum of 0.1% Al_2O_3 and 0.02% Fe_2O_3. Third-quality flint glass could contain only 95% SiO_2 and as high as 4% Al_2O_3. Only in the low-quality amber glass was the content of Fe_2O_3 permitted to reach 1%.

Most glass manufacturers established their own specifications for the physical size and chemical purity of the raw materials that have to be met by the suppliers of glass sand. In the past 10 years, glass manufacturers showed an increased interest in finer glass sands because processing of smaller particles required lower temperatures and, therefore, reduced the consumption of energy.

Foundry sands included molding sand and core sand that were used for casting iron-, aluminum-, and copper-base alloys. Required properties included cohesiveness sufficient to hold together the mold or core when moist, which is achieved by a bonding agent; refractoriness to withstand the high temperature of the molten metal; strength to resist the weight of the metal; permeability to release vapors and gases generated during cooling of the metal; and proper texture and composition to produce a smooth casting that will not react with the metal. Most metals were cast in "green sand," which is a mixture of silica and clay, although to a lesser extent, resins or oils were also used as a bonding agent instead of clays. In the case of naturally bonded foundry sands, the amount of clay minerals present affected their usefulness. Standard tests and specifications for foundry sands were published by the American Foundrymen's Society.[8 9]

Refractory sands were used in the manufacture of silica brick and tile, quartzite (gannister) being the commonly used raw material. Required properties were "the capability of maintaining the desired degree of chemical and physical identity at high temperatures" and resistance to abrasion, impact, thermal shock, and high level of load. Refractory silica materials were classified based on their general composition and on their distinctive properties. Standard classifications and specifications for Silica Refractory Brick were published by the ASTM.[10 11]

Abrasive sands were quartz sands used in stone sawing, glass grinding, metal polishing, and sand blasting. No rigid specifications existed for these sands, but sound, clean, hard, and closely sized sand grains were required. Purity and grain-shape specifications varied with the type of abrasive action and the requirements of the final product. An angular particle shape with sharp cutting edges was generally required.

Hydraulic fracturing sand was pumped into oil or natural gas wells as a sand-liquid mixture to break up petroleum-bearing formations and act as a propping agent, allowing oil or gas to move more freely toward the producing wells. Some of the major requirements for fracturing sands were spherical, well-rounded grains of clean, dried, and well-screened quartz sand, free of any materials such as feldspar, calcite, and clay. The most common size was 20/40 mesh; other sizes included 6/12, 8/16, 12/20, 40/70, and 70/140, but these sands represented only about 15% of the total sand used as proppant. "Recommended Practices for Testing Sand Used in Hydraulic Fracturing Operations," published by the American Petroleum Institute, was used as a guide by industry.[12]

Ground sand or silica flour is found wide industrial application as a filler in paint, plastics, rubber, ceramics, and a variety of other products. Mainly because of the diversity of its uses, no standard specifications existed for the silica flour used in most of these applications except grain size and chemical composition.

Metallurgical sand was used as a fluxing agent for basic oxides in various smelting operations and as a source of silicon in ferrosilicon manufacture. The ferrosilicon was a steel alloying additive. Filter sand was used extensively in filtering water for municipal and industrial use and swimming pools and in sewage treatment plants. Engine sand was used in locomotive haulage to improve traction. Other sands were used in special cements, in manufacturing silica brick and tiles for furnace linings and beds, for coal washing, and in manufacturing pottery.

Industry Structure

In 1989, 87 U.S. companies with 153 active operations produced silica sand. The individual industrial sand and gravel operations ranged in size from those producing about 1 million tons annually to those reporting less than 10,000 tons per year. Most of the production came from large operations that were mostly owned or operated by a small number of companies. In the past 10 to 15 years, there was a gradual trend toward larger operations, mostly because small plants were becoming less economical. The viability of small operations was dependent on demand in local markets, mining conditions, and the degree of processing required to supply the final product.

During the past 10 years, changes within the structure of the industrial sand industry occurred, primarily caused by mergers and acquisitions, some resulting from an influx of foreign capital, mostly from Europe.

Geology-Resources

U.S. resources of industrial sand were expected to be sufficient to meet domestic demand in the foreseeable future, although their geographic distribution and quality often did not match market requirements. The availability of these reserves was controlled to a significant degree by land-use and/or environmental constraints. Reserves of industrial sand owned or controlled by domestic producers were estimated to total about 3 to 4 billion tons.

Although industrial sand reserve data for the rest of the world were not available, it could be assumed, on the basis of geologic evidence, that world reserves were sufficient to meet demand, even if not always at the locations where needed.

Industrial sand or silica sand was produced in the United States from a variety of geological formations ranging in age from late Precambrian to mid-Tertiary. About 70 stratigraphic units were known as having an economic potential for this industry. Lithologically, these deposits ranged from quartzites, sandstones with different degrees of cementation, quartz conglomerates, chert deposits, and quartz pegmatites to terrace sands and gravels and dune sands. Most of the high-quality industrial sand was produced from a few geological formations in the eastern United States. Oriskany sandstone, or more precisely the Ridgeley formation of Early Devonian age, was one important source of silica sand. It extended from New York State to southern Virginia and eastern Ohio but

was being mined only in central Pennsylvania, northwestern Maryland, and northern West Virginia, where the formation was thick enough to be of commercial value. It was a hard white orthoquartzite with medium to fine, angular and subangular, and well-sorted grains. The St. Peter sandstone of Middle Ordovician age, extending from Wisconsin and Minnesota through Iowa, Illinois, and east-central Missouri, was another major source of industrial sand. The best known center of production of silica sand from this formation was the Ottawa district of La Salle county, IL, where it was known as "Ottawa sand," and to a lesser degree in southern Wisconsin and east-central Missouri. It was a soft and poorly cemented high-purity orthoquartzite with coarse, rounded grains. The weak cement holding the silica grains together was mostly a light-colored clay.

In addition to the two formations just mentioned, the most important sources of industrial sand in the United States, numerous other deposits were also being mined for silica sand in different parts of the country, including the Jordan sandstone of Upper Cambrian age in Minnesota and Wisconsin, a primary source of hydraulic fracturing sand; the Raritan formation of Upper Cretaceous age in central New Jersey and the Cohansey sand of probable Miocene age in southern New Jersey; the Tuscarora quartzite of Lower Silurian age in Pennsylvania and Virginia used for the manufacture of refractory bricks; the Sylvania sandstone of Devonian age in the Detroit area; the Oil Creek and McLish formations of Lower Ordovician age in Oklahoma, a southwestward extension of the St. Peter sandstone; and the Hickory sandstone of Cambrian age in central Texas that produced mostly hydraulic fracturing sand.

In the west, the most important sources of industrial sand were the Ione formation of Eocene age in northern California, the Silverado (Paleocene) and Tejon (Eocene) formations in southern California, and the Eureka quartzite of Middle Ordovician age in central California.

Approximately two-thirds of the U.S. industrial sand or silica sand was produced east of the Mississippi River, especially in the industrialized areas of the East North Central, South Atlantic, and Middle Atlantic regions. Of the top five producing States that accounted for about one-half of 1989 production, three—Illinois, Michigan, and New Jersey—were in the East and the other two—California and Texas—were in the West. The concentration of the industrial sand operations in the eastern part of the United States resulted from the existence of high-quality geologic deposits in close proximity to the major consuming industries, glass and foundry.

Technology

Exploration.—A large number of geologic formations with economic potential as a source of industrial sand have been mapped and described in the literature over many years and were, therefore, well known. Consequently, detailed exploration and development work for new industrial sand operations was expected to occur on some of these formations. The qualities of a silica deposit necessary for a viable operation should include proper particle size, chemical composition, degree of cementation, and deposit uniformity. Also, the nature and amount of waste material and the economic feasibility of its removal and possible use or disposal should be studied. The evaluation of the new deposit should also include an environmental impact study as required by most local or State agencies before authorizing a new mining operation.

If the raw material should prove to meet the requirements and adequate reserves are demonstrated, the development stage of the operation could be started. Economic feasibility and marketing studies should be performed by analyzing all factors important for any such mining operations, including the availability of power and water supply, mining and processing costs and requirements, the condition of nearby roads and highways, the proximity of rail haulage, the cost of compliance with local, State, and Federal regulations, and the proximity and density of local population as well as its attitude toward such a project.

Mining.—Most industrial sand was mined from open quarries, but a few underground operations existed, mostly because of an exceptionally thick overburden or environmental limitations. Surface mining methods and equipment varied with the type of the geologic formation, size and configuration of the deposit, production capacity, estimated life of the operation, and location of the deposit with respect to urban centers. The mining methods depended primarily on the degree of cementation of the rock, but most open pit mining operations included site clearing and removal of the overburden; mining of the silica rock or sand; processing of the material, including crushing, screening, and classification; and reclamation of the extraction area. Unconsolidated sands, such as the Cohansey of New Jersey, if below the ground water level were dredged. Much of the St. Peter sandstone was first loosened by light blasting and then washed down by hydraulic jets or "monitors" into sumps, from which it was pumped to the processing plants. Harder rock such as the Oriskany sandstone required blasting and primary and secondary crushing before it could be processed.

Beneficiation.—Processing of mined silica sand required specialized operations that varied considerably with the nature of the deposit and the physical and chemical requirements of the desired product. Depending on the degree of cementation, several stages of crushing were necessary to achieve the desired size reduction. Gyratory crushers, jaw crushers, impact mills, or roll crushers were used as primary or secondary crushers, and smooth rolls, media mills, autogenous mills, high-speed hammer mills, or fluid energy jet mills were used for grinding the product down to 50 microns and finer. Dry or wet screening was used to separate particles of sizes down to about 150 microns, and wet or air classifiers processed particles from 250 microns into the submicron range. Vibratory screens and gyratory screens in addition to mechanical, hydraulic, or air classifiers were used, depending on the size distribution required.

Research for the silica mining industry related not only to new methods that increased output and reduced production costs but also to health and safety problems as well as exploration, land management, and reclamation. Equipment manufacturers and some government agencies were constantly working on improving exploration, mining, and proc-

essing plant technology.

Significant technological developments instrumental in maintaining adequate production at relatively stable real costs were mostly in the processing plant technology. The use of computerized systems in plant operation and quality control increased; and this, along with improved mining and processing equipment, permitted the recovery of salable fractions that were previously considered uneconomical.

Recycling.—Recycling of silica sands was limited to some foundry sands, particularly those used for making cores and molds with no-bake resin-bonded sands, some abrasive and air-blasting sands, and some scrap glass that substitutes for glass sand. International trends toward increased recycling of glass and foundries sands and innovative ideas on recycling other materials should influence increased recycling of silica products.

Byproducts and Coproducts

Small amounts of gold and silver were recovered occasionally as a byproduct or coproduct from some unconsolidated silica sand deposits. Also, during the processing of some silica resources, other minerals, including clays, feldspars, mica, and quartz crystals, were produced as byproducts and coproducts.

Economic Factors

Silica sand deposits are nonrenewable resources. New mining methods combined with advances in mineral processing that were introduced during the past decade have increased the number of silica deposits that can be commercially developed.

The industrial sand industry was very competitive largely because silica sand is a relatively abundant mineral, with supply usually exceeding demand. The delivered price of the product, in addition to quality, was a very important element in any major transaction. The producer with an operation closest to the market had a significant advantage over competitors. Combining sophisticated (and therefore expensive) processing equipment backed by technical knowledge and solid sales expertise was important. For this reason, only a small number of large companies were able to compete successfully and succeed in the silica sand business and supply a wide variety of products. Smaller, less efficient operations became uneconomical as operating costs, as well as costs associated with meeting various Federal, State, and local regulations, continued to increase. The only alternatives they had were to either limit the range of products they supplied to closely located markets or go out of business.

Prices.—As a result of rapidly rising costs of labor, energy, and mining and processing equipment, 1988 constant dollar prices of industrial sand rose steadily between 1973 to 1983. From 1984 to 1989, 1988 constant dollar prices fluctuated in the 13.50 to 14.50 range. Prices should be expected to continue to fluctuate although they should slowly rise as a result of the cost of compliance with more stringent environmental, land use, and safety regulations.

Costs.—Production costs for silica sand were determined to a large extent by the cost of labor, equipment, energy supply, water availability, and the additional burden of compliance with environmental and safety regulations. Production costs varied widely depending upon the nature of the geologic deposit, the geographic location, and the type and number of products produced. Profits were relatively small for most producers, total production costs being close to the f.o.b. selling price per ton.

Tariffs.—There has been no tariff on imported silica sand, containing 95% or more SiO_2 and not more than 0.6% iron oxide, from most favored nations since January 1, 1987. For all other countries, the tariff for imported silica sand remains $1.94 per long ton.

Depletion Provisions.—The depletion allowance for industrial sand and gravel was 14%.

Operating Factors

Environmental Requirements.—Major environmental considerations that had to be dealt with in mining and processing of industrial sand and gravel were emission of particulate matter into the air, discharge of processing water, and noise abatement. Air pollution constituted a major problem in the processing plants, especially in the drying and packaging stages of finer products like silica flour, silicosis being the major disease that can be contracted as a result of long-term exposure to silica dust. Because of the high cost of compliance with the environmental regulations designed to reduce this health hazard and possible long-term liabilities associated with it, some companies were no longer producing silica flour or did not plan to produce it in the future. Both wet and dry methods of dust control were used. The most important water pollutant was clay in suspension as a result of washing and screening silica sand. Because of the large quantities of water used to process silica sands and the need of compliance with stringent regulations, the treatment of discharge water by the sand producer was expected to require increasingly sophisticated and expensive processing methods. Significant progress was made in reducing noise pollution both inside and outside of the operations, including noise and vibration produced by blasting and movement of heavy trucks.

Sand producers had to obtain mining permits from the appropriate governmental agency, which sometimes also required an Environmental Impact Statement (EIS) and a reclamation plan that met its guidelines or regulations. More and more emphasis was being put by local communities on improving the overall appearance of the operating mines as well as on land reclamation after mining was completed. At the same time, industry and the communities had to recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards. Many States, counties, and towns had zoning laws that regulated land use.

Most of the active silica sand quarries as well as the known deposits were on private land, which was either owned or leased on a long-term basis by the producers. These deposits contained high-quality silica sand and were in the best locations with respect to markets. Unlike the construction sand and gravel industry, the industrial sand industry was usually not significantly affected by increasing land values near populated areas.

Transportation.—Transportation costs for silica sand were often equal or considerably greater than the cost of the product at the processing plant. Because of the large variety and number of consumers of silica sand, long-distance haulage was not uncommon. The largest tonnage, 58% of all industrial sand, was shipped by truck because most users require a versatile and rapid delivery system. Substantial quantities, 34% of the total, were also shipped by rail, especially when large volumes were sent long distances.

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